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(58) Field of search

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(54) Removing nitrogen oxides from exhaust gases

(57) Nitrogen oxides are removed from exhaust gases containing oxygen and moisture by bringing the gas into contact with hydrogenated zeolite catalysts optionally impregnated with copper, zinc, vanadium, chromium, manganese, iron, cobalt, nickel, rhodium, palladium, platinum, or molybdenum, in the presence of organic compounds. The zeolite is e.g. a Y type, L type, or offretite-erionite ferrierite, mordenite, clinoptilolite, or ZSM-5 types. Organic compound can be a hydrocarbon, alcohol, ketone or ether. Exhaust gas is especially from an engine e.g. diesel or gas turbine.

*claims 15, 16  
102 on claims 23 and 24 "other than a beta structure"*

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METHOD FOR REMOVING NITROGEN OXIDES  
FROM EXHAUST GASES

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method of treating exhaust gases, especially those discharged from diesel engines, gas engines or gas turbines which contain excess oxygen and moisture as well as nitrogen oxides (abbreviated as  $\text{NO}_x$  hereinafter). The method comprises bringing the exhaust gas into contact with zeolite catalyst in the presence of organic compounds, thereby converting  $\text{NO}_x$  in the exhaust gas into harmless nitrogen gas.

Description of the Prior Art

There are several practical methods for removing  $\text{NO}_x$  from exhaust gases. For example, the selective reduction method is applied to exhaust gases from boilers which employs the  $\text{V}_2\text{O}_5\text{-TiO}_2$  catalyst and ammonia gas as the reducing agent. The method applied to exhaust gases from gasoline engines consists of controlling the air-fuel ratio (hence the oxygen concentration) and removing  $\text{NO}_x$ , carbon monoxide, and hydrocarbons all at once by the use of the ternary catalyst. (See Funahiki and Yamada, "Catalysts for Automotive Exhaust Gas", Preprints of the Meeting for Theoretical Fundamental Study of Practical Catalysts,

Catalysis Society of Japan, p. 15 - 20, 1989.) The former method has an advantage of being effective for exhaust gases containing excess oxygen, but it has also a disadvantage of requiring ammonia gas as the reducing agent. Therefore, it is useful for special applications but not for general uses. Especially, it can hardly be applied to automobiles carrying a diesel engine of compression ignition type and to small- or medium-sized stationary boilers. The latter method using the ternary catalyst is not effective for exhaust gases containing excess oxygen and hence it is not of practical use for exhaust gases from diesel engines.

#### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for removing  $\text{NO}_x$  effectively which can be applied to exhaust gases containing excess oxygen without the need of using ammonia.

This object is fulfilled by using as the catalyst hydrogenized zeolites as such or hydrogenated zeolite catalysts impregnated with one or more kinds of metals selected from the group consisting of copper, zinc, vanadium, chromium, manganese, iron, cobalt, nickel, rhodium, palladium, platinum, and molybdenum, in the presence of organic compounds. Thus, according to the present invention, it is possible to remove selectively nitrogen oxides from exhaust gases containing excess oxygen.

### DETAILED DESCRIPTION OF THE INVENTION

According to the present invention, hydrogenated zeolites are used as catalyst or catalyst support. The hydrogenation of the zeolite is carried out either by a direct method or an indirect method. The former method involves the steps of washing the zeolite with mineral acids repeatedly and exchanging cations in the zeolite with hydrogen ions. The latter method involves the steps of washing the zeolite with ammonium ion-containing water repeatedly, replacing cations in the zeolite with ammonium ions, and calcining the zeolite thereby volatilizing ammonia. Both the methods can be used for the present invention.

One of the most important features of the present invention is to use hydrogenated zeolites. Zeolite without hydrogenation removes  $\text{NO}_x$  very little as demonstrated in Example 1 and Comparative Example 1 which follow. There are no restrictions as to the species of the zeolites to be used in the present invention; it may be either synthetic one or naturally occurring one, so long as it is hydrogenated.

It is well known that the acid resistance of a zeolite depends on the silica/alumina ratio which indicates the chemical composition of the zeolite, and that the smaller the silica/alumina ratio, the lower the acid resistance. It is also known that hydrogenated zeolites are hydrophobic and have the properties of

solid acids, the strength of which depend also on the silica/alumina ratio. (See Course of Catalysts, vol. 10, compiled by the Catalysis Society of Japan, published by Kodansha, 1986.) These facts may suggest that the activity of catalysts supported on zeolites will greatly vary depending on the silica/alumina ratio. The present inventors found from many experiments on a variety of zeolites that desired catalysts in the present invention are obtained by hydrogenating zeolites having a silica/alumina ratio higher than about 5, as demonstrated in Examples 1 and 2 that follow. In addition, more active catalysts are obtained by hydrogenating zeolites having a silica/alumina ratio higher than about 10, as demonstrated in the same examples.

According to the present invention, the hydrogenated zeolite catalyst can be prepared by hydrogenating a synthetic zeolite (such as zeolite of Y type, zeolite of L type, zeolite of offretite-erionite mixed crystal type, zeolite of ferrierite type, zeolite of mordenite type, and zeolite of ZSM-5 type) or a natural zeolite (such as zeolite of mordenite type and zeolite of clinoptilolite type), as shown in Examples. They are exemplary but not limitative.

According to the present invention, the catalyst is used in the presence of organic compounds as reducing agent. The organic compounds include hydrocarbons such

as methane, ethane, propane, butane and fuel oil as well as alcohols, ketones, and ethers. In other words, the method of the present invention permits a much wider selection of reducing agent than the conventional selective reduction method which resorts to ammonia as the reducing agent.

The impregnation of metallic elements on the zeolite may be accomplished by stirring the hydrogenated zeolite (prepared as mentioned above) in an aqueous solution of salts of desired metallic elements followed by separating from the solution, and drying and calcining the treated zeolite. (This method will be referred to as the first impregnation method.) Alternatively, the impregnation may be accomplished by contacting the zeolite with an aqueous solution of salts of desired metallic elements and then with water containing ammonium ions and finally heating the treated zeolite for volatilizing ammonia. (This method will be referred to as the second impregnation method.) The second method may be performed by reversing the order of contacting. (This method will be referred to as the third impregnation method.)

In Examples explained later, experiments were carried out using synthetic zeolites of TSM series produced by Toso Co., Ltd., which include zeolites of Y type, L type, offretite-erionite mixed crystal type, ferrierite type, mordenite type, and ZSM-5 type. These

zeolites were hydrogenated by dipping in 4N hydrochloric acid at 100°C for 4 hours and then thoroughly rinsing and drying. Experiments were also carried out using natural zeolites, which include mordenite-containing tuff (from Akita Prefecture) and clinoptilolite-containing tuff (from Fukushima Prefecture). The natural zeolites were hydrogenated by washing repeatedly with heated hydrochloric acid (2 mol/L) for 40 hours.

The catalytic activity of the hydrogenated zeolites, with or without metallic elements supported thereon, were tested in the following manner. The powder of the hydrogenated zeolite was molded under pressure, then crashed and sieved to collect particles with diameters between 10 - 20 mesh. The sample (5 cm<sup>3</sup>) was filled in a stainless steel reactor tube 10 mm in inside diameter. Through this reactor tube was passed a simulated exhaust gas composed of 0.15 vol% NO, 10 vol% oxygen, and 7.3 vol% moisture, with the balance being argon. As an organic compound as the reducing agent, propane was added into this exhaust gas in an amount equivalent to 4 - 5 times the concentration of NO<sub>x</sub> (in molar ratio). The concentrations of NO<sub>x</sub> in gases were measured by the chemiluminescence method. The percentage of NO<sub>x</sub> removed was calculated according to the formula below;

$$100(\%) - \frac{A}{B}$$

where, A = concentration of  $\text{NO}_x$  in the gas discharged  
from the catalyst layer

B = concentration of  $\text{NO}_x$  in the gas entering the  
catalyst layer

5        The invention will be more clearly understood with  
reference to the following Examples and Comparative  
Examples.

Example 1 (Removal of  $\text{NO}_x$  by hydrogenated zeolite  
catalysts)

10        Experiments on the removal of  $\text{NO}_x$  by a variety of  
hydrogenated zeolite catalysts were carried out. The  
results are shown in Table 1. In these experiments, the  
temperature of the reactor was kept at  $400^\circ\text{C}$  and the  
flow rate of the simulated exhaust gas was 210 mL per  
15       minute (equivalent to the space velocity of  $2500 \text{ hr}^{-1}$ ).  
It is noted from Table 1 that the percentages of  $\text{NO}_x$   
removed are zero in the cases of zeolites having  
silica/alumina ratios lower than 10 and that the  
percentages of  $\text{NO}_x$  removed are higher than 30% in the  
20       cases of zeolites having silica/alumina ratios higher  
than 12. The results indicate that the hydrogenated  
zeolites themselves can remove  $\text{NO}_x$  from the exhaust gas  
containing excess oxygen so long as the zeolites have  
silica/alumina ratios higher than about 10 and the  
25       exhaust gas is incorporated with an organic compound as  
the reducing agent.



Table 1

Type of zeolite	Silica/alumina ratio	Percentage of NO <sub>x</sub> removed (%)
Y type	5.9	0
L type	6.2	0
Offretite-erionite mixed crystal type	7.4	0
Mordenite type	10.2	1
Ferrierite type	12.2	34.0
Mordenite type	14.9	35.0
Ferrierite type	20.5	41.0
ZSM-5 type	40.0	40.0

Example 2 (Removal of NO<sub>x</sub> by metal-impregnated hydrogenated zeolite catalysts)

Experiments were carried out in the same manner as in Example 1 using a variety of catalysts impregnated with one or more metals selected from among nickel, copper, manganese, chromium, cobalt, zinc, iron, and vanadium. The results are shown in Table 2. It is noted from Table 2 that hydrogenated zeolites become more active when they are impregnated with metallic elements. The percentage of NO<sub>x</sub> removed is higher than 20% even when the silica/alumina ratio is lower than 10 (except in the case of zinc catalyst). And the percentage of NO<sub>x</sub> removed is higher than 60% if the silica/alumina ratio is higher than 10 (except in the

case of zinc catalyst). Thus the percentage of  $\text{NO}_x$  removed is greatly increased when hydrogenated-zeolites are impregnated with metallic elements.

Table 2

	5	Metallic element supported	Kind of carrier*	Silica/ alumina ratio	Percentage of NO <sub>x</sub> removed (%)	Conversion into nitrogen gas (%)
	10	Copper	A B C D	5.9 12.2 14.9 40.0	100 <del>100</del> 100 100	100 <del>99</del> 100 100
	15	Vanadium	A B C D	5.9 12.2 14.9 40.0	33.6 86.8 84.5 86.2	100 100 99 99
	20	Chromium	A B C D	5.9 12.2 14.9 40.0	29.7 46.7 42.7 49.3	97 99 99 100
	25	Manganese	A B C D	5.9 12.2 14.9 40.0	81.1 97.9 89.2 99.1	100 100 99 100
	30	Cobalt	A B C D	5.9 12.2 14.9 40.0	20.7 <del>77.3</del> 88.4 89.8	98 <del>100</del> 97 99
	35	Nickel	A B C D	5.9 12.2 14.9 40.0	66.2 99.8 87.8 99.9	100 100 100 100
	40	Zinc	A B C D	5.9 12.2 14.9 40.0	13.7 23.5 22.3 23.0	97 96 95 98
	45	Iron	A B C D	5.9 12.2 14.9 40.0	25.4 66.5 65.7 68.3	92 100 100 97

Att'y argues  
the U.O.O.S.I.  
T. A. would  
choose copper  
rather than  
cobalt.

\* A: Y type, B: ferrierite type, C: mordenite type,  
D: ZSM-5 type

Example 3 (Effect of space velocity on the removal of  
NO<sub>x</sub> by metal-impregnated zeolite catalysts)

Similar experiments to those in Example 2 were  
carried out using copper catalysts or copper-nickel  
5 catalysts to examine the effect of space velocity on the  
removal of NO<sub>x</sub>. No water vapor was added to the  
simulated exhaust gas in these experiments. The results  
are shown in Table 3. It is noted that catalysts on  
zeolites having a silica/alumina ratio lower than 10  
10 achieve the percentage of NO<sub>x</sub> removed higher than 50%  
even when the space velocity is increased eight-fold  
(up to 20,000 hr<sup>-1</sup>). In the case of catalysts on  
zeolites having silica/alumina ratios higher than 10,  
the percentage of NO<sub>x</sub> removed is higher than 90% at the  
15 same space velocity.

Table 3

	Metallic element supported	Zeolite (silica/ alumina ratio)	Space velocity (hr <sup>-1</sup> )	Percentage of NO <sub>x</sub> removed (%)	Conversion into nitrogen gas (%)
5	Copper	Type Y (5.9)	5000	100	100
10			10000	96.2	100
			15000	64.5	99
			20000	51.6	98
15		Ferrierite type (12.2)	5000	100	100
			10000	100	100
			15000	100	100
			20000	96.4	99
20		Mordenite type (14.9)	5000	100	100
25			10000	100	100
			15000	98.6	97
			20000	87.3	98
30		ZSM-5 type (40.0)	5000	100	100
			10000	100	100
			15000	100	98
			20000	97.6	99
35	Copper- nickel	Type Y (5.9)	5000	100	96
			10000	100	100
			15000	92.5	100
			20000	63.2	98
40		Ferrierite type (12.2)	5000	100	100
			10000	100	97
45			15000	100	99
			20000	93.2	100
50		Mordenite type (14.9)	5000	100	100
			10000	100	96
			15000	100	100
			20000	98.8	99
55		ZSM-5 type (40.0)	5000	100	100
			10000	100	100
			15000	100	95
60			20000	99.1	97

Example 4 (Identification of reaction products)

The exhaust gas treated by the present catalysts may contain nitrous oxide ( $\text{N}_2\text{O}$ ) and nitric acid as well as nitrogen gas. To identify these compounds, the  
5 treated exhaust gas was analyzed. Since the simulated exhaust gas does not contain nitrogen gas, it is possible to calculate the conversion of  $\text{NO}_x$  into nitrogen from the amount of nitrogen produced. The determination of nitrogen and nitrous oxide was carried  
10 out by gas chromatography. The determination of nitric acid was carried out by alkali titration of the condensate recovered from the treated gas by cooling by ice. It was found that the amounts of nitrous oxide and nitric acid were smaller than the limit of  
15 detection.

In Tables 2 and 3, the conversion of  $\text{NO}_x$  into nitrogen gas is expressed in percentage calculated under the assumption that 2 mol of  $\text{NO}_x$  removed gives rise to 1 mol of nitrogen gas. It is noted that the metal-  
20 impregnated catalysts of the present invention convert  $\text{NO}_x$  into nitrogen gas almost completely.

Example 5 (Denitration by natural mordenite)

Experiments of denitration were carried out using metal-impregnated catalysts prepared from natural  
25 mordenite (from Akita Prefecture) treated by the direct hydrogenation. The metal impregnation was accomplished by the above-mentioned first method. The direct

hydrogenation was accomplished by washing natural mordenite repeatedly with 2N hydrochloric acid at 100°C for 40 hours. The metals impregnated on the catalysts were prepared mostly from nitrates (except palladium chloride, rhodium chloride, chloroplatinic acid, ammonium metavanadate, and ammonium molybdate). For metal impregnation, the catalyst was dipped in the aqueous solution (1 mol/L) of a volume three times as much as that of the catalyst, at 90°C for 2 hours.

The conditions of experiments were as follows: The catalyst bed was prepared by filling a column, 2 cm in inside diameter and 16 cm high, with catalyst particles, 10 - 20 mesh in size. The simulated exhaust gas was passed at a flow rate of 1 liter per minute. The simulated exhaust gas was composed of N<sub>2</sub> (80 vol%), O<sub>2</sub> (10 vol%), CO<sub>2</sub> (10 vol%), NO (0.17 vol%), and moisture produced by injecting 4 g of water per hour into the gas. The gas was preheated to the reaction temperature and incorporated with an organic compound as the reducing agent.

The results are shown in Table 4. Propane used as the reducing agent is a fuel-grade commercial produce composed of 92% of propane, 8% of ethane, and 0.1% of isobutane. Gas oil is a commercial product for diesel cars. Other organic compounds are commercial reagents.

Table 4

	Element supported	Reaction temperature (°C)	Name of reducing agent	Amount added (mg/min)	Ratio of Denitration (%)	Remarks
5	None	430	None	0	8	O <sub>2</sub> = 5%
	None	430	Propane	3.8	55	
	None	430	Gas oil	4.3	47	
10	None	350	Gas oil	4.3	45	
	None	430	Gas oil	4.3	47	
	None	500	Gas oil	4.3	41	
	None	430	Ethanol	6.0	57	
	None	430	Ethylene	4.0	50	
15	None	430	Acetone	5.0	47	
	None	430	n-C <sub>10</sub> H <sub>22</sub>	7.0	55	
	None	430	Ether	5.0	47	
	None	430	Isobuthane	4.0	50	
20	Copper	400	None	0	8	
	Copper	500	None	0	6	
	Copper	600	None	0	3	
	Copper	400	Propane	3.8	34	
	Copper	500	Propane	3.8	36	
25	Copper	500	Propane	3.8	36	
	Copper	600	Propane	3.8	38	
	Copper	600	Propane	8.0	61	
	Copper	600	Propane	11.4	74	
	Copper	500	Ethanol	6.0	40	
30	Copper	500	n-C <sub>10</sub> H <sub>22</sub>	7.0	50	
	Copper	500	Ether	5.0	45	
	Copper	500	Acetone	5.0	48	
	Chromium	430	None	0	15	
	Chromium	430	Propane	3.8	52	
35	Nickel	430	None	0	63	
	Nickel	430	Propane	3.8	83	
	Nickel	430	Gas oil	4.3	50	
	Nickel	430	n-C <sub>10</sub> H <sub>22</sub>	5.0	75	
	Nickel	430	Ethanol	5.0	60	
40	Iron	430	None	0	7	
	Iron	430	Propane	3.8	62	
	Cobalt	430	None	0	27	



Table 4 (continued)

	Element supported	Reaction temperature (°C)	Name of reducing agent	Amount added (mg/min)	Ratio of Denitration (%)	Remarks
5	Cobalt	430	Propane	3.8	68	O <sub>2</sub> = 5%
	Cobalt	430	Gas oil	4.3	50	
	Cobalt	430	Ethanol	5.0	70	
10	Palladium	400	None	0	18	
	Palladium	500	None	0	18	
	Palladium	430	None	0	10	
	Palladium	430	Propane	3.8	55	
	Palladium	430	Propane	3.8	67	
15	Manganese	430	None	0	10	
	Manganese	430	Propane	3.8	75	
	Manganese	430	Propane	3.8	78	
	Manganese	430	Gas oil	4.3	50	
	Manganese	430	n-C <sub>6</sub> H <sub>14</sub>	6.0	65	
20	Manganese	430	n-C <sub>10</sub> H <sub>22</sub>	7.0	60	
	Manganese	430	Ethanol	6.0	58	
	Manganese	430	Ethylene	4.0	70	
	Manganese	430	Acetone	5.0	65	
	Manganese	430	n-Butane	4.0	70	
25	Manganese	430	Isobutane	4.0	70	
	Molybdenum	430	None	0	10	
	Molybdenum	430	Propane	3.8	51	
	Molybdenum	430	Gas oil	4.3	45	
	Rhodium	430	None	0	15	
30	Rhodium	430	Propane	3.8	51	
	Rhodium	430	Gas oil	4.3	40	
	Platinum	430	None	0	10	
	Platinum	430	Propane	3.8	55	
	Platinum	430	Gas oil	4.3	46	
35	V-Mn binary	300	None	0	15	
	V-Mn binary	400	None	0	11	
	V-Mn binary	300	Propane	3.8	27	
	V-Mn binary	400	Propane	3.8	89	
	V-Mn binary	400	Propane	7.3	95	

Table 4 (continued)

	Element supported	Reaction temperature (°C)	Name of reducing agent	Amount added (mg/min)	Ratio of Denitration (%)	Remarks
5	V-Mn binary	500	Propane	3.8	85	
	V-Mn binary	400	Gas oil	4.3	60	
10	Cr-Mn binary	430	Propane	3.8	44	
	V-Ni binary	430	None	0	9	
	V-Ni binary	430	Propane	3.8	62	
	Cr-Ni binary	430	None	0	16	
	Cr-Ni binary	430	Propane	3.8	46	
	Cr-Ni binary	430	Gas oil	4.3	33	
15	Cr-Cu binary	300	None	0	0	
	Cr-Cu binary	400	None	0	16	
	Cr-Cu binary	250	Propane	3.8	4	
	Cr-Cu binary	300	Propane	3.8	10	
	Cr-Cu binary	430	Propane	3.8	27	
20	Cr-Cu binary	300	Gas oil	4.3	27	
	Cr-Cu binary	320	Gas oil	4.3	36	
	Cr-Cu binary	430	Gas oil	4.3	27	
	Cr-V binary	300	None	0	7	
	Cr-V binary	330	None	0	8	
25	Cr-V binary	360	None	0	25	
	Cr-V binary	300	Propane	3.8	36	
	Cr-V binary	330	Propane	3.8	61	
	Cr-V binary	360	Propane	3.8	63	
	Cr-V binary	300	Gas oil	4.3	27	
30	Cr-V binary	360	Gas oil	4.3	22	
	Cr-Fe binary	300	None	0	7	
	Cr-Fe binary	330	None	0	14	
	Cr-Fe binary	360	None	0	6	
	Cr-Fe binary	380	None	0	6	
35	Cr-Fe binary	430	None	0	4	
	Cr-Fe binary	300	Propane	3.8	58	
	Cr-Fe binary	330	Propane	3.8	78	
	Cr-Fe binary	380	Propane	3.8	58	
	Cr-Fe binary	430	Propane	3.8	46	
40	Cr-Fe binary	300	Gas oil	4.3	52	
	Cr-Fe binary	330	Gas oil	4.3	55	
	Cr-Fe binary	380	Gas oil	4.3	33	
	Cr-Fe binary	430	n-C <sub>10</sub> H <sub>22</sub>	5.0	78	

Example 6 (Denitration by natural clinoptilolite)

Similar experiments as in Example 5 were carried out except that the catalysts were prepared from clinoptilolite (from Fukushima Prefecture). Results are shown in Table 5.

Table 5

	Element supported	Reaction temperature (°C)	Name of reducing agent	Amount added (mg/min)	Ratio of Denitration (%)	Remarks
10	None	430	Propane	3.8	40	
	None	430	Gas oil	4.3	40	
	None	430	n-C <sub>10</sub> H <sub>22</sub>	7.0	50	
15	None	430	Ethanol	6.0	54	
	None	430	Ether	5.0	43	
	None	430	Isobutance	4.0	40	
	Iron	430	None	0	10	
	Iron	430	Propane	3.8	40	
20	Iron	430	Gas oil	4.3	30	
	Chromium	430	None	0	10	
	Chromium	430	Propane	3.8	44	
	Chromium	350	Gas oil	4.3	43	
	Chromium	430	Gas oil	4.3	50	
25	Chromium	520	Gas oil	4.3	40	
	Manganese	430	None	0	8	
	Manganese	430	Propane	3.8	67	
	Manganese	430	Ethanol	6.0	60	
	Manganese	430	Gas oil	4.3	45	
30	Manganese	430	n-C <sub>10</sub> H <sub>22</sub>	7.0	50	
	Nickel	430	None	0	51	
	Nickel	430	Propane	3.8	70	
	Nickel	430	Gas oil	4.3	45	
	Cr-Fe binary	430	None	0	10	
35	Cr-Fe binary	330	Propane	3.8	65	
	Cr-Fe binary	430	Propane	3.8	40	
	Cr-Fe binary	330	Gas oil	4.3	47	
	Cr-Fe binary	380	Gas oil	4.3	40	

Example 7 (Denitration by catalysts hydrogenated by  
the indirect method)

In this example the same raw material and  
impregnation method as in Example 5 were used except  
5 that the hydrogenation was carried out by the indirect  
method in the following manner. Natural mordenite rocks  
were crushed, and the resulting powder was dipped in an  
aqueous solution of ammonium chloride (2 mol/L) at 90°C  
for 2 hours. The powder was then heated to 600°C to  
10 volatilize ammonia. The results are shown in Table 6.

Example 8 (Effect of the second impregnation method)

The catalyst was prepared from the natural  
mordenite as in Example 5. The zeolite was caused to  
support a desired metallic element and then hydrogenated  
15 by the ammonium ion exchange according to the  
above-mentioned second impregnation method. The  
results are shown in Table 6.

Example 9 (Effect of the third impregnation method)

The catalyst was prepared from the same zeolite as  
20 in Example 5. The zeolite was caused to support a  
desired metallic element according to the  
above-mentioned third impregnation method. The results  
are shown in Table 6.

Table 6

Example No.	Element supported	Reaction temperature (°C)	Name of reducing agent	Amount added (mg/min)	Ratio of Denitration (%)
7	None	430	None	0	0
7	None	430	Propane	3.8	59
7	None	430	Gas oil	4.3	32
7	Manganese	430	None	0	3
7	Manganese	430	Propane	3.8	69
7	Manganese	430	Gas oil	4.3	55
7	Iron	430	Propane	3.8	40
7	Copper	430	Propane	3.8	35
8	Manganese	430	None	0	10
8	Manganese	430	Propane	3.8	67
8	Manganese	430	Gas oil	4.3	35
9	Manganese	430	Propane	3.8	86
9	Nickel	430	None	0	5
9	Nickel	430	Propane	3.8	59

Comparative Example 1 (Removal of  $\text{NO}_x$  by unhydrogenated zeolites)

Experiments were carried out under the same conditions as in Example 1 except that the zeolite was not hydrogenated. The results are shown in Table 7.

It is noted that only very little  $\text{NO}_x$  was removed.

Comparative Example 2 (Removal of  $\text{NO}_x$  by hydrogenated zeolite catalysts in the absence of organic compounds)

Experiments were carried out under the same conditions as in Example 1 except that the organic compound as the reducing agent was not added. The results are shown in Table 7. It is noted that only very little  $\text{NO}_x$  was removed.

Comparative Example 3 (Removal of NO<sub>x</sub> by metal-impregnated hydrogenated zeolite catalysts in the absence of organic compounds)

Experiments were carried out using metal-impregnated catalysts under the same conditions as in Example 2 except that no organic compound as the reducing agent was added. The results are shown in Table 7. It is noted that the percentage of NO<sub>x</sub> removed was less than 10%.

Table 7

Zeolite	Silica/ alumina ratio	Removal of NO <sub>x</sub> (%)		
		Comparative Example 1	Comparative Example 2	Comparative Example 3
A	5.9	0	0	3
B	12.2	1	7	0
C	14.9	0	0	4
D	40.0	2	5	9

Designation of zeolite:

A: Zeolite of Y type

B: Zeolite of ferrierite type

C: Zeolite of mordenite type

D: Zeolite of ZSM-5 type

WHAT IS CLAIMED IS:

1. A method for removing nitrogen oxides from exhaust gases containing oxygen and moisture which comprises bringing the exhaust gas into contact with hydrogenated zeolite catalysts or hydrogenated zeolite catalysts impregnated with one or more kinds of metals selected from the group consisting of copper, zinc, vanadium, chromium, manganese, iron, cobalt, nickel, rhodium, palladium, platinum, and molybdenum, in the presence of organic compounds.

2. A method for removing nitrogen oxides from exhaust gas as claimed in Claim 1, wherein the zeolite catalyst is a zeolite having a silica/alumina ratio of 5 or above.

3. A method for removing nitrogen oxides from exhaust gas as claimed in Claim 1 or Claim 2, wherein the zeolite catalyst is any one of zeolite of Y type, zeolite of L type, zeolite of offretite-erionite mixed crystal type, zeolite of ferrierite type, zeolite of mordenite type, zeolite of clinoptilolite type, and zeolite of ZSM-5 type.

4. A method for removing nitrogen oxides from exhaust gases as claimed in Claim 1, Claim 2, or

Claim 3, wherein the organic compounds are hydrocarbon, alcohol, ketone or ether.

5. A method for removing nitrogen oxides from exhaust gases, substantially as described in the Examples.



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